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# Report of the West Coast Satellite Time Series Advisory Group

A circular black ink stamp. The outer ring contains numbers 0 through 9 repeated twice. In the center, it reads "JUN 1985" at the top, followed by "RECEIVED" in large bold letters, and "NASA SSI FACILITY ACCESS DEPT." in smaller bold letters below it. A small star symbol is positioned above the date.

**Jet Propulsion Laboratory**  
California Institute of Technology  
Pasadena, California

# **Towards a Study of Synoptic-Scale Variability and Dynamics of the California Current System**

**Report of the West Coast Satellite Time  
Series Advisory Group**

April 1, 1985



National Aeronautics and  
Space Administration

**Jet Propulsion Laboratory**  
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Pasadena, California

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### Executive Summary

Satellite imagery of near-surface phytoplankton pigment concentrations and sea surface temperature has been demonstrated to be extremely useful in the study of mesoscale variability in the ocean. Extension of these studies to larger, synoptic scales appears promising. The development of time series of pigment and temperature imagery spanning the entire California Current System is essential for the study of many compelling scientific questions. These questions involve the large-scale dynamics of biological and physical processes that cannot be adequately examined using only ship and other in situ measurements. We will need the unique ability of satellites to provide the repeated, synoptic, high-resolution data necessary to observe the high degree of temporal and spatial variability in the California Current System. The first use of such time series would be to characterize, descriptively and statistically, the patterns of large-scale variability. These results will then be used along with in situ data and modeling efforts to help understand the large-scale dynamics of the California Current System.

We recommend that such time series be developed to address these questions concerning both biological and physical processes. Development of these time series should be coordinated through a project established at the Jet Propulsion Laboratory under the scientific direction of Mark R. Abbott and managed by Philip M. Zion. Such a project will acquire the raw digital data (level 1) and develop a browse file and catalog. Production of the remapped, geophysical data (pigment and temperature) will take place at several locations and will be coordinated through the JPL time series project, with the ultimate goal of producing complete time series (from approximately 20°N to 60°N and 105°W to 140°W, encompassing the lifetime of the Coastal Zone Color

Scanner). We anticipate that most of this level 3 processing will take place at JPL. The JPL time series project will provide high resolution mesoscale data and reduced resolution large-scale data mosaics to the JPL Pilot Ocean Data System for archiving and distribution. Any analysis of the time series will be done by individual investigators or investigator teams. Such analysis will require strong interdisciplinary cooperation.

Such time series will prove extremely useful for a global Ocean Color Imager program from both a scientific and practical standpoint. Scientifically, a CZCS time series will extend the length of any future OCI time series. It will also focus scientific attention on large-scale processes, as well as provide large amounts of fully processed satellite imagery to oceanographers who previously only had limited access to such data. This project would also address issues of data base management and distributed processing, as well as the production of a consistent data set over a long time period. Such abilities will be essential for any future global missions as well.

## 1.0 Introduction

As a result of the launch of the Coastal Zone Color Scanner (CZCS) aboard Nimbus 7 and with subsequent improvements in geophysical algorithms, it is possible to determine near-surface phytoplankton pigment concentrations from space to within about a factor of two (Ocean Color Science Working Group 1982; Gordon, Clark, Brown, Brown, Evans, and Broenkow 1983a). Similarly, the Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA Tiros satellite series can make routine measurements of sea surface temperature (SST) to within about 1.0°C (Bernstein 1982). These accuracies are adequate to address many scientific questions. Several investigators on the west coast have been using AVHRR and CZCS imagery routinely, generally concentrating on a particular geographic area, such as Pt. Arena or the Southern California Bight (e.g. Abbott and Zion 1985; Smith, Eppley, and Baker 1982), or on a particular research program such as the Optical Dynamics Experiment (ODEX), Ocean Prediction Through Observation, Modeling, and Analysis (OPTOMA) (e.g. Rienecker, Mooers, Hagan, and Robinson 1985), or the U.S. Coastal Ocean Dynamics Experiment (CODE) (e.g. Kelly 1983). A larger-scale study of the California Current System was undertaken by Peláez-Hudlet (1984). In addition, there have been applications of satellite imagery to fishery problems in the California Current System (e.g. Laurs, Fiedler, and Montgomery 1984). These studies have used time series of satellite images to study various physical and biological processes at particular space and time scales dictated by the regional nature of the data and the sampling frequency of available, usable images.

In view of the increasing availability of high quality SST and pigment images from several areas of the California Current System, the Oceanic Processes Branch of NASA Headquarters established a West Coast Satellite Time



Series Advisory Group to consider the following issues:

- o Is there a scientific rationale for extending current CZCS-AVHRR time series to a larger spatial and temporal domain on the west coast of North America?
- o What are the scientific and data processing requirements for such time series?
- o How will this work relate to other oceanographic programs, both within and outside of NASA?
- o What are the implications for acquisition, production, validation, archival, distribution, and analysis of such time series?
- o What further action should be taken to address the above issues?
- o Who should be responsible for this work (and exactly what work should be done)?

The group met on 19-20 July 1984 at Scripps Institution of Oceanography, La Jolla, California. The following report summarizes their conclusions. A list of participants is in Section 8.0.

## 2.0 Scientific Rationale

### 2.1 Previous work

Eastern boundary currents have long been known to be regions of high productivity and major fisheries, a result of generally favorable conditions for upwelling of nutrient-rich water into the euphotic zone (e.g. Smith 1968). Such currents are also quite variable on a variety of time and space scales in both physical and biological processes. This variability, coupled with the productivity of the system, has provided both scientific and societal reasons for studies of eastern boundary currents. One such system is the California Current System off the west coast of North America.

The California Current System has been studied extensively on both a regional and large-scale basis (Hickey 1979). (We define regional or mesoscales as length scales of 10-500km and time scales of 2-100 days and large scales as length scales of 100-3000km and time scales of 100 days to several years.) Beginning in 1949, large-scale studies were undertaken by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) in response to the collapse of the California sardine fishery (Reid, Roden, and Wyllie 1958). Although the temporal and spatial frequency of sampling has varied over the years, this data set has shown the importance of large-scale and basin-wide fluctuations to the biological and physical dynamics of the California Current System. For example, interannual changes in southward flow (Bernal and McGowan 1981; Chelton, Bernal, and McGowan 1982), possibly driven by changes in the eastern tropical Pacific circulation, seem to be responsible for changes in zooplankton biomass. Large-scale seasonal variability in the California Undercurrent has also been examined (Chelton 1984). The large-scale spatial distribution of zooplankton (Chelton 1982) appears to be related to upwelling

driven by the curl of the wind stress. Within such a system, classical biological interactions (such as competition and predation) may not play dominant roles in determining abundances or composition because of the disruptive effects of variable physical processes (McGowan 1971, 1974).

Regional studies, which are more commonly conducted in oceanography, as opposed to the large-scale CalCOFI studies, have also been undertaken in the California Current System. These studies have focused on a variety of physical and biological processes. For example, OPUS (Organization of Persistent Upwelling Structures) concentrated on the upwelling center near Point Conception, California (Jones, Brink, Dugdale, Stuart, Van Leer, Blasco, and Kelley 1983); OPTOMA (Ocean Prediction through Observation, Modeling, and Analysis) examined the effects of mesoscale variability off northern California (Mooers and Robinson 1984; Robinson, Carton, Mooers, Walstad, Carter, Rienecker, Smith, and Leslie 1984); U.S. CODE (Coastal Ocean Dynamics Experiment) focused on the wind-driven circulation on the continental shelf near Point Arena, California (CODE Group 1983); and Canadian CODE studied the interaction of physical and biological processes on the shelf off Vancouver Island (e.g. Freeland, Crawford, and Thomson 1984). In addition to these large, intensive field programs, there have been several long series of less extensive measurements, such as the Department of Energy studies in the Southern California Bight (e.g. Eppley, Renger, and Harrison 1979) and off the Washington coast (e.g. Hickey and Hamilton 1980). Finally, there have been numerous single expeditions to various regions in the California Current System (e.g. Simpson, Koblenz, Haury, and Dickey 1984). This is certainly not a complete list of the research programs that have been conducted in the California Current System in the past decade; however, it demonstrates that there has been a mixture of intensive regional studies, long term, less extensive regional studies, and

very long term, large-scale studies.

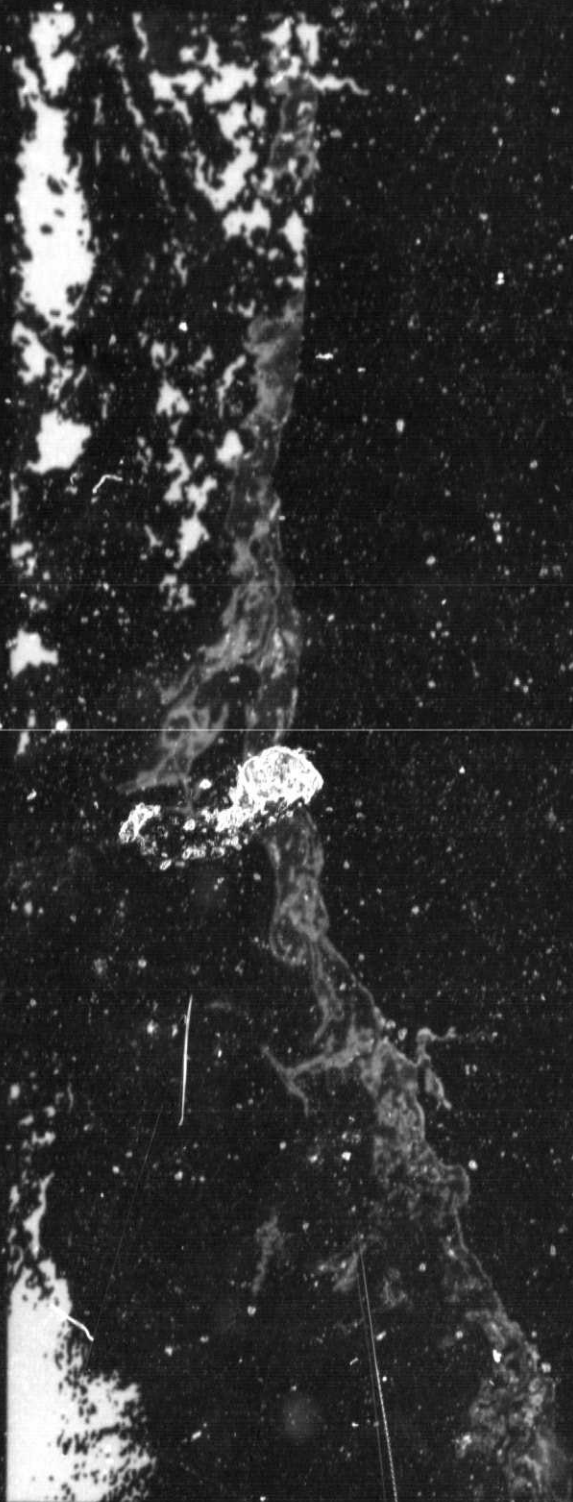
Time series of CZCS and AVHRR imagery have been used for studying many of these mesoscale phenomena, particularly energetic processes that are difficult to sample with ships and buoys. For example, Kelly (1983) used AVHRR images to study coastal dynamics during CODE; Rienecker et al. (1985) used AVHRR imagery to identify and track a cool jet during a ship survey; Ikeda and Emery (1984) used time series of AVHRR images to describe and model meanders; Bernstein, Breaker, and Whritnor (1977) studied an eddy in the California Current System using several data sets, including satellite imagery; Traganza, Silva, Austin, Hanson, and Bronsink (1983) inferred nutrient distributions from SST images off the central California coast. Abbott and Zien (1985) studied the kinematics of an upwelling event during CODE using CZCS and AVHRR imagery. Further progress in the understanding of the mesoscale dynamics is expected from continued studies combining in situ and satellite measurements. Regional scale satellite imagery has also been applied to a number of fishery studies in the California Current domain (e.g. Laurs et al. 1984).

## 2.2 Large-Scale studies

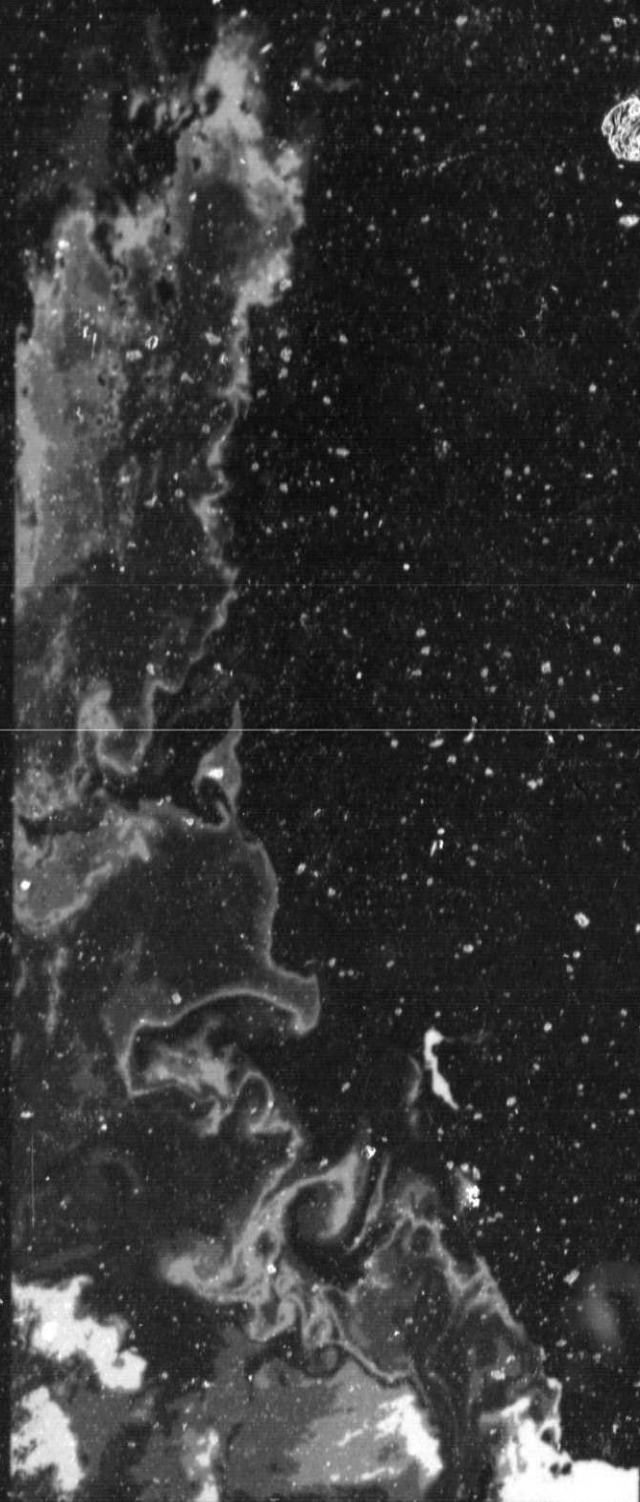
The study of the California Current System as a complete system will require satellite imagery to avoid the obvious problems of synopticity of sampling. Figure 1 shows a synoptic view of the California Current System with a large portion of the system in view of the satellites. The inherent variability and extent of the system make it unlikely that combining previous regional studies will provide the necessary data to study large-scale processes. Even the CalCOFI program (among the largest field programs we can imagine) has been limited in its temporal and spatial sampling such that many issues of large-

Figure 1. Sea surface temperature (derived from NOAA-6 AVHRR) and near-surface phytoplankton pigment concentrations (derived from Nimbus 7 CZCS) from 7 July 1981. The SST image was collected eight hours after the pigment image. White and black areas in the SST image are clouds; white areas in the pigment image are clouds.

ORIGINAL PAGE  
COLOR PHOTOGRAPH



PIGMENT



TEMPERATURE

scale dynamics (both biological and physical) cannot be resolved (e.g. Chelton 1982, 1984). We will need the unique ability of satellites to provide nearly synoptic, high-resolution images (using both single images and mosaicking several clear images) of large areal extent. Combined with existing in situ data sets, such satellite time series will allow a number of important questions pertaining to the dynamics of the California Current System as a whole to be addressed.

Development of large-scale satellite time series has been hindered by data acquisition and processing problems, rather than by any lack of scientific interest. These problems are now surmountable; data from the Scripps Satellite Oceanography Facility (SSOF) are relatively complete and are currently being duplicated and archived at the Jet Propulsion Laboratory; several locations for data processing have been developed on the west coast in recent years so that processing of large data sets is feasible. It is essential that these resources be exploited and the time series be developed so that cooperative scientific investigations of the large-scale biological and physical dynamics of the California Current System may begin. Failure to develop the time series would represent a missed opportunity for the first adequately sampled study of large-scale processes in oceanography.

There are many questions concerning the large-scale biological and physical dynamics of eastern boundary currents. These studies fall into two basic categories. First, there are descriptive questions that relate to the characterization of the California Current System. For example, we are unable to tell whether the observed patterns in Figure 1 are persistent from season-to-season or from year-to-year. Second, there are questions that relate to dynamics which will require the answers to the descriptive questions and the

integration of satellite and surface data as well as theoretical and modeling studies. For example, the dynamics of the offshore filaments in Figure 1 are only beginning to be investigated. The following questions were identified at the meeting:

- o What are the seasonal statistics of large-scale variability?

Such information will be extremely valuable to modeling efforts.

While such a question seems straightforward, it cannot be answered with present in situ measurements.

- o What is the role of seasonal forcing in maintaining the observed features? For example, the large cross-shore jets in Figure 1 appear to be related to the spring upwelling season. Analysis and modeling by Ikeda, Mysak, and Emery (1984) and Ikeda and Emery (1984) suggests that there is a definite seasonal signal in the observed patterns of sea surface temperature.

- o What is the relative importance of persistent offshore eddies and jets in the energetics and dynamics of the California Current System? How persistent are some of these "persistent" features? What are typical periods of these features? For example, observations of an eddy by Simpson and co-workers showed that some eddies persist for at least several months (Simpson et al. 1984); Ikeda et al. (1984) showed varying time scales for some offshore jets. Do similar features exist west of the California Current System?

- o What is the relationship between persistent features and coastal topography? The large, offshore jets are related to variations



in the coastline topography (Kelly 1983) and have been described by Ikeda et al. (1984).

- o What are the longshore coherence and phase relationships of variability? Freeland and Denman (1982) presented evidence that the spin-up of a topographically-trapped eddy on the shelf off Vancouver Island may be related to the spring transition in surface winds off Cape Mendocino (Huyer 1983). Such relationships will give extremely useful information on the dynamics of the California Current System.
- o What are the coherence and phase relationships between variability in the California Current System and other areas of the Pacific Ocean? Enfield and Allen (1980) and Chelton and Davis (1982) showed systematic variations in sea level along the west coast of North America that were related to variations in the eastern tropical Pacific. Other data sets, such as Station P, might show fluctuations that are coherent with fluctuations in the California Current System. Another interesting question is whether any offshore phase propagation can be detected (as suggested from models which show westward propagation of coastal signals in the form of Rossby waves).
- o Are there detectable surface manifestations of a poleward undercurrent? If so, what role do undercurrents play in maintaining seemingly persistent features? Localized high productivity on the Vancouver Island shelf is related to the upwelling of the California Undercurrent (Freeland and Denman 1982), for example. The interaction of bottom topography and the undercurrent may lead to surface variability

(Ikeda et al. 1984).

- o Can pigment and SST isopleths satellite imagery be used to show large-scale flow patterns? Kelly (1983) demonstrated that a reasonable picture of the velocity field can be derived from SST images. Such information on the flow field will be valuable for mesoscale and large-scale circulation models.
- o What is the relationship between the the coastal region and the offshore open ocean? Mooers and Robinson (1984) inferred large cross-shore transports of materials, heat and momentum off Point Arena; Traganza et al. (1983) also showed large exchanges between coastal and open ocean waters.
- o What is the large-scale coherence between SST and pigment? Since these are two different (but related), nonconservative tracers, we expect that their patterns of variability should differ (Denman 1983; Bennett and Denman 1985).
- o What is the relationship between wind stress, longshore transport, pigment, and zooplankton distributions? This question will require ancillary surface measurements, particularly those from CalCOFI. Chelton et al. (1982) demonstrated a relationship between zooplankton abundance and longshore transport; we need to understand the phytoplankton pigment component as well.
- o What is the relationship of physical forcing to fluctuations in large-scale primary productivity? The CalCOFI sampling surveys are an attempt to understand this question as it pertains to fish yields, although sampling limitations have restricted its investigation.

The availability of satellite time series will complement these field studies so that some answers to this question may be possible. In particular, is there a persistent band of high primary productivity 200km offshore as speculated by Chelton (1982)?

- o Along with field data, can long time series of pigment images improve our understanding of the relationship between pigment and primary productivity? Eppley, Stewart, Abbott, and Heyman (1985) showed that the relationship varied considerably over time and from region to region; continued work in this area will be important to understanding large-scale productivity in the California Current System.
- o What is the temporal distribution of phytoplankton biomass? How does variability in this distribution affect success of larval fish classes? On a small scale, Lasker (1975) showed a direct relationship between survival success and phytoplankton variability. Extension of this work to the large-scale productivity of the California Current System is crucial to understanding biological dynamics in this region.
- o What is the relationship of the near-surface patterns observed by satellites with processes occurring at depth? Kelly (1983) showed that SST imagery was representative of the surface mixed layer.
- o What is the degree of coupling between large-scale, mesoscale, and small scale events? What is the relationship between large-scale eddy variability and California Current meanders to the smaller scale squirts and jets? Davis (1985a,b) proposed that

small-scale coastal circulation is strongly influenced by eddy processes.

- o What are the large-scale similarities and differences between the California Current System and other eastern boundary currents? While the answers to this question will be speculative as a result of the relatively limited data sets available from other eastern boundary currents, areas of future research may be delineated.
- o Is the historical satellite data set sufficient to begin to create a consistent picture of interannual variability? It is unlikely that any statistically reliable relationships can be inferred from the relatively short time series; however, the AVHRR and CZCS data sets do cover periods of significant changes in the California Current System so that some interannual variability can be described. These data sets also form a building block on which long time series can be built (using OCI and AVHRR) so that, eventually, interannual variability can be studied.

### 2.3 Continued mesoscale studies

The relationship of mesoscale processes to larger scale dynamics is an area of much research at present (Wunsch 1981; Robinson 1983). The separation of research areas into large and mesoscale studies in this report is somewhat artificial; complete understanding of processes at both scales is required. However, most ship and satellite studies have been regional in extent. In regards to satellite studies, usually areas of 500km x 500km are considered. A specific event or geographic region is studied, such as an upwelling center, or a ship cruise study area. Such regional data sets are easier to process as

a result of their limited extent. Although satellite imagery may not have the absolute accuracies nor the necessary high frequency sampling required to address all questions of mesoscale processes, it has been shown that time series of regional scale images can be extremely useful (e.g. Kelly 1983). Long time series of regional scale imagery can provide a sufficient quantity of data to perform many quantitative statistical analyses, despite the problems of gappy coverage and small-scale variability that result from errors in processing algorithms. Studies of the following mesoscale questions should be included in any large-scale study.

- o What is the relative importance of open ocean wind stress curl-induced upwelling, coastal (Ekman divergence) upwelling, bottom topography, and coastline shape in upwelling zones? For example, Kelly (1983) showed that coastline shape was important in the location of upwelling centers; Chelton (1982) proposed that wind stress curl was more important than coastal wind-driven upwelling to large-scale variations in the California Current.
- o What is the "life history" of upwelling centers? What are the typical pigment, SST relationships in such centers? Can such information be used to improve models of upwelling? Jones et al. (1983) presented a model for the development of temperature-nutrient-pigment concentrations in an upwelling center; Abbott and Zion (1985) showed that such centers develop too rapidly for ship sampling.
- o What is the life history of mesoscale eddies? What are the decorrelation length and time scales for mesoscale variability in the SST and pigment fields? How do these decorrelation scales

affect ship measurements? Such scale information will help in the development of models of tracer dispersal in mesoscale turbulence (e.g. Bennett and Denman 1985) and the design of superior in situ sampling strategies.

- o Can the different spatial-temporal distributions of SST and pigment be used to understand the flow characteristics and phytoplankton growth rates? Although both SST and pigment are nonconservative tracers, pigment is a passive scalar. Differences in the behavior of these two tracers in mesoscale flow may allow us to separate the effects of phytoplankton growth and fluid flow. First attempts at modeling these processes have been made by Bennett and Denman (1985).

The above list is by no means a complete set of potential areas of investigation. Rather, long time series of satellite images will provide a sufficient quantity of data for quantitative statistical analyses in a number of regional studies. They also form the basis upon which continued time series can be built with future satellite missions.

### 3.0 Programmatic Rationale

The unique capabilities of satellite image data -- long time series of repeatable, synoptic, high-resolution coverage -- allow previously intractable problems to be studied. The AVHRR series will continue and be improved in the next decade. As the CZCS is expected to be operational for only a few more years, the Ocean Color Science Working Group (1982) has proposed that an Ocean Color Imager (OCI) be flown in the next decade. The continued study of the historical CZCS data set will aid the OCI in four ways. First, it will

demonstrate the feasibility of using satellite data for scientific studies such as those outlined in Section 2. Second, it will provide additional experience in data analysis techniques. Third, the data processing experience gained between now and the OCI launch will benefit the design of the processing and analysis effort for OCI data. Fourth, such a CZCS time series will be added to the OCI west coast time series, thus extending the length of the series.

Since the thrust of the OCI will be global measurements of pigment concentration, the experience gained in accomplishing the proposed large-scale west coast studies will be invaluable. This work is an essential step, moving from the mesoscale and regional processing of today toward the global processing required for the OCI effort. Such problems as distributed data processing, data base management, and data distribution for a large data set must be overcome for the west coast series, as well as consistent processing for data covering a long time period. Most importantly, the west coast time series effort will focus scientific attention on large-scale phenomena and develop and refine adequate data processing and analysis tools to cope with questions of this scale.

#### 4.0 Requirements

##### 4.1 Statement of the problem

Only a small fraction of west coast oceanographers wishing to use CZCS and AVHRR data have direct access to registered, geophysical data products (either pigment or SST). Those without such access are effectively precluded from using these data sets. The only useful archives at present are level 1 (digital, raw satellite data). The effort required to set up a facility to

convert these data to level 3 (registered, geophysical units) requires much time and money. Level conversion requires a superminicomputer plus image display hardware and a software system that is at least the functional equivalent of the O.B. Brown - R.H. Evans system at the University of Miami. This is clearly out of the reach of most research budgets. One alternative is to receive processed level 3 data from one of the small number of sites with conversion capability. Despite the obvious drawback that an investigator cannot select the data to be processed, this is taking place on a limited, informal basis. Little data are distributed because the "producer" facility is established on a single-investigator scale. At this level of effort, it is unreasonable to expect that "consumers" can be provided with much more than tape copies of preprocessed data. Clearly, any increase in processing demand would overwhelm this network. Simply stated, the processing bottleneck for west coast data is now at the geophysical conversion step, rather than at the level 1 data acquisition step (for which an adequate level 1 archive exists).

#### 4.2 Scientific requirements

The primary requirement is to develop and make available complete, consistently processed level 3 pigment and SST time series from the west coast of North America. There are five steps in this process: acquisition, production, validation, distribution, and archiving. Analysis of these time series will be considered separately.

It is essential that these time series be developed under close scientific guidance. The large amount of data requires that processing not be done solely on the basis of investigator interest; rather, data should be processed simply on the basis of available processing capability. However, scientific management is necessary so that the series are consistent over time and to



ensure the scientific integrity of the time series. Within reasonable limits, time series production should strive for the highest level of accuracy and reliability.

#### 4.3 Acquisition

The west coast of North America is probably the best sampled area in the world in terms of CZCS and AVHRR data. Many of the data tapes are physically located on the west coast, simplifying data acquisition. The first step is to assess the holdings of the two largest west coast archives. These are, in order of priority, SSOF and the Visibility Laboratory (VISLAB). There are several advantages of SSOF over VISLAB: presence of both CZCS and AVHRR data; data in swath format (about ten minutes per pass rather than two minute scenes); continuously updated, machine-readable inventory; simple procedures for data copying and processing at JPL; virtually all data are from the west coast. Currently, up to 50 tapes per week are being copied at JPL from the SSOF archive. Another level 1 archive, the NOAA/NESDIS facility at Redwood City, California, is a viable alternative for near-real time AVHRR data. This facility captures AVHRR data farther north than SSOF (but with considerable overlap) and is an operational facility that captures all passes (and will continue to capture such satellite passes). Disadvantages are a lack of historical data and reduced radiometric resolution for the data collected there. However, full radiometric resolution data are presently being acquired at Redwood City under the guidance of R.L. Bernstein. Another limited facility exists at the University of British Columbia under the direction of W.J. Emery. It can collect AVHRR data as far north as the Beaufort Sea.

As clouds and gaps in initial data acquisition effectively reduce the available data to about 50% of the theoretical maximum (all clear scenes,

always acquired and available), it is essential that all possible data be entered into the time series. This will ensure adequate data for the study of mesoscale processes and to ensure at least minimal coverage for larger areas.

#### 4.4 Level 3 production

Production is the generation of level 3 geophysical, earth-gridded products from level 1 data. Level 3 data should be the final, universally available product, as these data will be the starting point for analysis. This will minimize duplication of computation and possible divergence of differently generated level 3 data at the earlier processing stages. In addition, the level 3 products should have a cloud and land mask available. Cloud masking with the AVHRR data must be clearly defined (e.g. Kelly 1985).

The level conversion and data exchange formats must be well-documented. Procedures and formats should be standardized to the maximum extent possible. Resolution of data format and processing compatibility issues requires further discussion by the level 3 producers. Issues to be discussed include: comparisons of geophysical processing algorithms, definition of uniform grid sizes and projections, resource estimates for data format standardization, requirements and resource estimates for further pre-analysis processing (e.g. compositing images for large-scale studies), data acquisition and distribution plans, and content and format of documentation.

Some form of distributed processing between these various level 3 "producers" is desirable. While this ensures that there is scientific supervision during the level 3 production stage, it will be necessary to coordinate processing so as to avoid duplication and inconsistencies. A data base management system is required so that the various nodes in this processing system

can easily determine what processing has been done to any particular piece of the time series. Within this distributed processing network, it is essential that there be a central or coordinating node so that a complete time series is produced with as few gaps in coverage as possible.

#### 4.5 Validation

The geophysical algorithms are currently under development, particularly for the CZCS. However, substantial progress has been made in the past two years. Algorithm developers have agreed on a period for which the CZCS degradation is well-understood (e.g. Gordon, Brown, Brown, Evans, and Clark 1983b; Mueller 1985), although recent work suggests the possibility of interannual instability in these algorithms as a result of changes in phytoplankton species assemblages. In general, processing of these data is standardized. However, algorithm intercomparison is required before distribution of level 3 products can begin. This will achieve two purposes: processing will be documented as part of the intercomparison, and estimates of variance as a result of differences in processing will be calculated. Such information is essential for the study of large-scale variability; natural variability must not be mistaken for processing variability or variability in sensor calibration.

Similar statements can be made for the AVHRR although the algorithms are perhaps better understood. However, it appears that algorithms must be developed on a regional basis, or at least account for varying air mass types (Kelly and Davis 1985). Also, variation between the five AVHRR sensors that have thus far been flown needs to be accounted for in processing. As the California Current System is a region of intense upwelling, the possible effects of low level stratus clouds and fog must also be understood. Accuracies of about 1°C are probably obtainable; this will probably suit the needs of most

large-scale studies.

There is a trade-off between increased accuracy in geophysical processing and expedient data availability. In the interest of timeliness, data distribution should begin as soon as intercomparisons are complete, with the proviso that algorithm refinement may proceed in parallel. This in turn requires a processing history for each data product. Another possible solution is to process data from years where algorithm behavior is well understood, e.g. the early years of the CZCS, non-E1 Chichón years for the AVHRR. The inclusion of accuracy limits with the level 3 data should help avoid propagation of spurious data. Flags for special situations such as low sun angles, edge of swath, mixed aerosol types, etc. are also needed. Validation efforts should continue as users of the level 3 data can relay valuable in situ comparisons to algorithm developers.

#### 4.6 Distribution and archival

There should be a central node on the west coast responsible for the distribution of the level 3 products. This central node will collect data from the other level 3 "producers." Data collection may be either level 1, with conversion to take place at the central node, or, when standardization and algorithm intercomparisons are successfully completed, level 3 products. The central node should distribute both regional and large-scale level 3 products (see 5.0 below). Therefore the central node will have the ability to accept both these products and to create large-scale products (by mosaicking) whenever adequate data exist. This function will include data maintenance services such as data catalog, physical storage of data, and data retrieval capabilities. Eventually, these data archiving and distribution tasks will be the responsibility of the JPL Pilot Ocean Data System (PCDS) or its successor.

PODS will accept and archive data, maintain on-line catalog and search capabilities, provide an on-line mechanism for data requests from remote sites, and, data transmission technology permitting, provide on-line access to the archived level 3 data. The central node will be responsible for processing level 3 data, accepting data from other processing sites, and furnishing these level 3 data to PODS.

It may be necessary for the central node to maintain an off-line data catalog and retrieval capability until PODS can assume these responsibilities. This will be done on an informal investigator-to-investigator basis.

#### 5.0 A Proposed Strategy

We recommend the following specific strategy to undertake the five-part process described above for the development and analysis of pigment-SST time series of the west coast of North America, including the California Current System.

Complete series of the available AVHRR-CZCS level 1 scenes from 20°N to 60°N and from 105°W to 140°W should be obtained from the period 1 January 1979 until the demise of the CZCS. (At the current time, it appears that the CZCS will function for at least one more year.) We support continued acquisition of west coast AVHRR data and west coast OCI data when they are available, with acquisition at SSOF and other sites.

The older tapes from SSOF (1979 and 1980) should be copied as soon as possible as they are near the end of their shelf life. About 5% of the older tapes are unreadable. Data acquisition should continue in chronological order so that loss of data as a result of tape degradation is minimized.

We recommend that the JPL pigment/temperature time series project continue as the lead center for level 1 data acquisition from SSOF and other archives. It should take the lead role in coordinating level 1 data acquisition and distribution with other processing facilities on a mutually agreeable basis. As part of this acquisition process, it is essential that a browse file be created to identify swath coverage and quality. A browse image will be produced for every swath in the JPL time series catalog. Such a browse file should be readily reproducible for distribution. A continuously updated level 1 data catalog is also necessary, listing the level 1 holdings at the various facilities. This catalog will be of the relational data base type, allowing searches by satellite and time. It is not required that this information be available on-line until PODS assumes responsibility for the catalog. There should be provisions for informal level 1 data distribution between the level 3 producers.

The JPL time series project should undertake this acquisition process because it has assembled many of the necessary resources: operations personnel and procedures for tape copying, storage, and retrieval; data base systems to inventory level 1 tapes and attributes; an engineer to maintain the data base; and a continuously updated photo file of all data swaths. The JPL project has the capacity to copy, store and inventory moderately large volumes of tapes (1500/year). In addition, the time series project is co-located with PODS so that it may take advantage of new data storage and distribution technologies being investigated by PODS, such as digital optical disks.

PODS (or its successor) should maintain an up-to-date and accurate catalog of level 1 holdings at the main archives, including at least SSOF, NESDIS, and the JPL time series project. Through its cooperative effort with the JPL

time series project, PODS has access to those level 1 tapes acquired by the project. With the permission of the project, PODS should make these data available to investigators interested in doing their own level 3 production. PODS should also be able to load and catalog browse images as they arrive from the JPL time series project and from other investigators. Loading will involve adding digital images of fixed size to an archive and creating catalog entries. Browse images may be stored in other forms, such as photos. Access requirements for these data, which are meant to be viewed as images, will depend on the hardware available to the user. Some cheap, easily reproducible medium such as microfilm rolls may be needed. For those with more sophisticated image display capabilities, it is necessary that the browse images be able to be transmitted as image files, preferably over telephone lines.

The production of level 3 data from level 1 data should take place on a distributed basis, with the JPL pigment/temperature time series project acting as the lead node or coordinator. In this system, the local nodes will continue to process segments of the time series (subsets in both time and space) as determined by investigator interest. These products will be collected at JPL after agreement with the individual investigators. Areas not covered will be processed at JPL. The JPL time series project should undertake this activity for the following reasons. The processing at JPL, while under scientific direction and supervision, will not be investigator-driven. That is, issues such as the order of data processing, processing standardization, and others will be derived from the requirements of the community at large and not from a single investigator. The goal will be to process the greatest amount of data while maintaining the scientific integrity and value of the data set. The JPL project will provide adequate computing and personnel resources to undertake this level conversion for the benefit of all investigators,

particularly those only interested in level 3 data who have had little or no access to such data in the past.

The suggested order of level 3 data production was determined by the availability of concurrent field data and issues of extraordinary interest. Considering the years 1979-1984, 1981 was selected as the first priority because of the relative abundance of field data from CalCOFI, U.S. CODE, Canadian CODE, OPUS, DOE studies in the Southern California Bight and off Washington, as well as other field programs. Processing algorithms are also well understood for this year. Availability of in situ data is a prime consideration in the selection of satellite data to be processed, reflecting the desire to coordinate satellite and field programs. Production of the level 3 should then continue in chronological order, beginning with 1979 data. However, as processing algorithms for data acquired since 1983 become better understood, it may be useful to process data from 1983 at an earlier stage as they overlap with the California El Niño (McGowan 1983).

To address the regional and large-scale oceanographic research areas described earlier, the JPL time series project should produce two types of level 3 data. One type will be the traditional regional data set, probably 512x512 pixels in extent (about 200,000km<sup>2</sup>), utilizing the full spatial resolution of the CZCS and AVHRR. The other type of level 3 data will be reduced-resolution mosaics using data from an entire swath. The reduced-resolution products will be on an 8km grid. The JPL project should process about 750 swaths per year in this manner.

It is probable that most of this "community" processing will be done by the JPL time series project. Other producer sites do not have the surplus computing capacity to undertake this effort in addition to their own research



needs. It will be the responsibility of the JPL project to maintain adequate computing resources for this task. In addition, most other producer sites are also algorithm development sites engaged in refinement of level conversion procedures. These sites are not necessarily oriented towards conversion of large numbers of swaths. Instead, they are actively pursuing greater accuracy in algorithm results. This involves detailed analysis of a relatively small amount of data. The JPL project will accept the results of these developers to keep its processing as accurate as possible, but it will concentrate on distributing high-quality data quickly.

The JPL time series project, under the scientific direction of Mark R. Abbott and managed by Philip M. Zion, should coordinate these activities, ensure data compatibility, and track progress in algorithm development, scientific results, and programmatic objectives. The lead node should also be responsible for mosaicking the various subsets, as well as other processing activities as determined by discussions with the other processing facilities. In addition, the lead node should take responsibility for the development of a data base management system for tracking the progress of a particular piece of data through the various processing stages.

Validation of the level 3 products will be the responsibility of the level 3 producer. As part of the data base management system, surface data should be available to assist in continuing algorithm development and verification. Algorithm intercomparisons should be continued between the various level 3 producers, perhaps with this time series project providing a focal point.

Level 3 data distribution and archival should be done through PODS (or its successor) with the advice of the JPL pigment/temperature time series

project. PODS should be able to load and catalog level 3 data products as they arrive from the JPL time series project and from other investigators. PODS must also provide search and extract capability for these data. Distribution of the data will depend in part on the requirements of the user. For those users with image display capabilities, it should be possible to send the level 3 data in the proper format. Although the required transmission times are not presently known, level 3 images need not be distributed as rapidly as browse images. Investigators may wish to receive tapes or digital optical disks for analysis and display on their local systems. As analysis of image data is greatly enhanced by having photographic products as well as the digital data, PODS should also produce and distribute a photographic atlas of the level 3 data as they are entered into the archive.

While this strategy includes all of the necessary steps for processing and distributing a west coast time series, the analysis of image data will require attention as well. Computing requirements for such analysis could far exceed the requirements for production. In addition, methods to handle data gaps, large data sets, etc. require considerable sophistication. As level 3 production is the current bottleneck in the use of satellite imagery, analysis and interpretation looms as the next bottleneck. Development of standalone image workstations is one valuable approach. Such workstations are within the budget range of individual investigators, including an image display capability. Transportable software is also required. While it is impossible to define specific software tools for analysis, it would be extremely valuable for PODS to help coordinate informally such software development, particularly in the area of portability to various computer systems.

In addition to software tools, it will also be necessary to have access

to field data sets. The year 1981 was selected as the first year of the time series in large part due to the availability of field data. The understanding of large ocean systems will require measurements at a variety of space and time scales; surface and satellite data sets will be complementary. Thus, it is essential that surface data also be available. The inclusion of ship data in the level 3 archive will depend on agreements between individual investigators and the JPL time series project. The project will assume responsibility for providing such data to PODS for inclusion in the level 3 archive. Continued analysis of field data sets is necessary for the understanding of the satellite data sets.

#### 6.0 Summary

With the increased availability of high quality SST and pigment images obtained from satellites, the development of a large-scale time series of such images from the west coast of North America appears feasible. With such a time series and associated surface measurements, investigators will be able to characterize the large-scale and mesoscale variability of the California Current System. This will allow the investigation of the underlying physical and biological processes responsible for the observed spatial and temporal variability.

We propose a strategy for the acquisition, production, validation, distribution, and archiving of such a time series. This strategy involves a distributed processing network, with a lead node at JPL to coordinate and manage this effort. Investigators will be able to access high quality, level 3 (gridded, geophysical units) products for analysis and examination of a wide range of oceanographic questions.

Such a strategy will involve a large number of oceanographers who currently have only limited access to level 3 satellite images. It will also initiate the investigation of large-scale processes that is only possible through the use of satellite data. This effort will help prepare the oceanographic community and NASA for the global data sets that will be obtained by the OCI and other sensors. It will also address key data processing and analysis issues for global image data sets.

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16. Abstract <p>A West Coast Satellite Time Series Advisory Group was established by the Oceanic Processes Branch of NASA Headquarters to consider the scientific rationale for the development of complete west coast time series of imagery of sea surface temperature (as derived by the Advanced Very High Resolution Radiometer on the NOAA polar orbiters) and near-surface phytoplankton pigment concentrations (as derived by the Coastal Zone Color Scanner on Nimbus 7). The Advisory Group was also to consider the scientific and data processing requirements for such time series.</p> <p>The Advisory Group determined that such time series were essential if a number of scientific questions regarding the synoptic-scale dynamics of the California Current system were to be addressed. These questions concerned both biological and physical processes. It was proposed that a time series project be established at the Jet Propulsion Laboratory to coordinate development of the time series. This would ensure the production of series that cover the entire California Current domain (from 20°N to 60°N and from 105°W to 140°W) and span the lifetime of the CZCS. Both a high-resolution (1 km) and reduced-resolution (10 km) series would be made available through the Jet Propulsion Laboratory Pilot Ocean Data System.</p>			
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